THE USE OF MACRO-INVERTEBRATES FOR POPULATION AND COMMUNITY MONITORING OF METAL CONTAMINATION - INDICATOR TAXA, EFFECT PARAMETERS AND THE NEED FOR A SOIL INVERTEBRATE PREDICTION AND CLASSIFICATION SCHEME (SIVPACS)

D. J. SPURGEON, R. D. SANDIFER and S. P. HOPKIN
University of Reading
Ecotoxicology Research Group
School of Animal and Microbial Sciences
P.O. Box 228, Reading, RG6 6AJ
United Kingdom

Abstract

The loss of species from a system will lead to changes in ecosystem structure, energetics and processes. Consequently, the changes in abundance and in particular the presence or absence of species from areas where they would normally be expected to occur should be the final measure of the biological impact of a pollutant. If such studies are to be useful for monitoring pollutant impact, the techniques should be simple and relatively quick to undertake. The number of taxa that can be incorporated into such studies may be limited to reduce time demands. Suitable indicator taxa should conform as closely as possible to the seven criteria outlined by Pearson which are described in this paper. Three taxa of terrestrial macro-invertebrates that appear to fit these criteria are oligochaeta, aranaea and isopods. Surveys of macro-invertebrate community structure were undertaken at sites contaminated with cadmium, copper, lead and zinc, situated around a smelting works. Results indicate that community sensitivity can vary considerably between taxa. Earthworms were relatively sensitive to metals, whilst no deleterious effect on the total catch, number of species or diversity of spiders was detected. As a consequence of the differential sensitivities existing between taxa, community resilience for any given group should not necessarily be regarded as evidence of ecosystem health. A broader based scheme developed with acknowledgement to RIVPACS offers a more suitable basis for assessing pollutant induced changes at the community level.

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1. Why monitor at the community level?

The role of biomonitoring is to indicate the "health" of ecosystems in which it is suspected that a biologically significant concentration of a pollutant has been released. As early as the 1950s, it was suggested that biological systems should provide the basis for environmental assessments [1, 2], as the extrapolation of effects from abiotic samples is confounded by a variety of biotic and non-biotic factors.

Hopkin [3] outlined four biological approaches for monitoring the effects of pollutants in ecosystems: 1) Assessing impact on community structure, 2) Measuring pollutant concentrations in the tissues of sentinel species, 3) Quantifying effects on individual performance, and 4) Detecting the presence of genetically altered races, resistant to pollutants. All these strategies have a role within any monitoring framework, for example, strategy 2 is useful for assessing the transfer of pollutants to higher organisms [3], strategy 2 for appraisal of effects on individual species such as beneficial arthropods [4] and strategy 4 for pesticide management [5].

It is our opinion that assessments of the health of ecosystems at contaminated and remediated sites should be made by determining changes in community structure at such sites. In particular, the absence of species from areas where they would normally be expected to occur should be considered a strong indication that deleterious effects have occurred. Changes in abundance or the removal of species will lead to changes in system energetics and ultimately, variations in systems processes and food webs [6]. Since the impact of pollutants on ecosystems will be derived from their cumulative effects on constituent species, the protection of community structure should ensure that the structure and function of the receiving ecosystem are preserved.

2. Why monitor with invertebrates?

There are a number of valid reasons for using invertebrate species for community monitoring. Major invertebrate groups are present over a range of diverse habitats, are relatively easy to sample and can be simple to identify when good keys are available [7]. In addition, the low mobility of some groups such as earthworms means they are representative of the habitat being sampled. This is not always the case for groups such as vertebrates.

Disadvantages of using terrestrial invertebrates include problems in species level identification, since the taxonomy of some groups is not clear [8], and limitations of the sampling techniques [9]. Additionally, sample processing and identification can be time consuming. Thus, the rapid enumeration of results from multiple site comparisons is impeded.

The implication of time constraints on the development of community monitoring will be discussed later in this chapter.

3. The development of community monitoring in aquatic and terrestrial systems

Community monitoring with macro-invertebrates has been widely used in aquatic systems. The earliest schemes were based on the clearly identifiable community responses that occur after the organic enrichment of freshwater. Sites were scored for contamination based on the presence or absence of species with presumed sensitivity to organic pollution [8, 10]. Although useful for assessing organic enrichment, score systems were not applicable for assessing the impact of a range of pollutants, since relative taxal sensitivities may vary.

The second generation of schemes concentrated on measuring the richness and equilibrity of distribution of individuals between species resulting in the development of diversity indices such as Shannon-Wiener's and Simpson's. Although these indices are still widely used for monitoring purposes, their usefulness is somewhat restricted, since conclusions from the various systems do not always correlate at the same sites and perhaps more seriously, it is not always clear that diversity decreases with increasing pollution [3]. For example, Bengtsson and Rundgren [11, 12] found a bell-shaped response of diversity for spiders, harvestmen, slugs, beetles, ants and springtails along a copper and zinc gradient with maximum diversity at intermediate concentrations.

The most recently developed community assessment scheme in aquatic systems is the River Invertebrate Prediction and Classification System (RIVPACS). This system uses a multi-variant model to predict the fauna of an unperturbed site of known character. Actual communities can then be compared to these targets allowing potential biotic effects of pollutants to be assessed [13]. This system allows predictions of relative abundances, biotic scores and species and family occurrence to be made. The system was developed in the UK and is now in routine used by regulatory authorities. The scheme has attracted interest from countries in both Europe and the rest of the world.

Community monitoring is at an earlier stage of development in terrestrial systems. It has long been recognised that contaminants can alter community structure in terrestrial ecosystems. For example, metal rich spoil tips of disused mines often support a distinct flora of tolerant or pre-adapted metallophytes [14], while alterations in the relative abundance of Collembola species have been found in contaminated regions [12, 15]. However, no strategy is currently in widespread use in Europe for monitoring the impact of chemicals using terrestrial invertebrates. The

success of such schemes in aquatic systems suggests the need to develop an assessment procedure applicable to the terrestrial environment.

For some groups of pollutants the most suitable communities for assessing environmental impact will be defined by the nature of the chemical under study. For example, the non-target effects of pesticides may be best monitored by measuring their effects on populations of selected beneficial invertebrates. In such circumstances the best techniques may be adapted from population biology. However, for pollutants with more general effects, simple population measurements are unlikely to be useful in determining effects, since it will not always be clear which species will be most sensitive for a given chemical and thus what should be monitored. For these pollutants, a more integrated system of monitoring is required.

4. Developing community monitoring in terrestrial ecosystems

Community monitoring studies with invertebrates have the potential to provide a widely applicable means of assessing the impact of pollutants. However, as outlined in Section 1, a number of problems exist in using invertebrates as monitoring organisms. As previously stated, a major limitation is the amount of time required for sampling, particularly if multiple sites are used to define response gradients. For this reason, previous studies have tended to focus on assessing effects on specific invertebrate groups [11, 12, 16, 17, 18]. The reduced workload required for such studies is likely to appeal to the regulatory agencies, as these organisations will demand monitoring schemes that are quick to undertake. However, the implications of limiting monitoring to a single group on the conclusions made from such studies have not been examined. Clearly, results from community studies could differ profoundly depending on what is monitored.

Pearson [19] has suggested that faunal groups suitable for community monitoring should correspond as closely as possible to the following criteria: 1) Taxonomy must be well known and stable, 2) Natural history must be well known, 3) They must be readily surveyable, easy to manipulate and identify, 4) Higher taxa (order, family, tribe and genus) must have a broad geographical distribution over a breadth of habitat types, 5) Lower taxa (species and subspecies) must be specialised and sensitive to habitat changes, 6) Taxa must have potential economic importance, 7) Patterns of biodiversity must be reflected in other related and unrelated taxa. Three taxa of terrestrial invertebrates that appear to fit these criteria well are earthworms, woodlice and spiders.

In Table 1 each of the three groups has been scored for each of Pearson's criteria to a maximum of five. No score for the relationships of

sensitivity between taxa has been awarded, since it is not clear if the concept of such relationships fits current ecotoxicological philosophies where ideas of a single representative "sensitive" species have largely been rejected. In general all three groups score well. The taxonomy of these groups can be considered reasonably stable (compared for example to springtails and mites) and they are well represented among the published keys [20, 21, 22]. The natural histories are well known [23, 24, 25, 26, 27, 28], and there are a number of standardised techniques existing for their survey. Higher taxa have a broad range of distribution, while particularly for spiders, species are sensitive to habitat differences. Earthworms are of economic importance as they maintain soil fertility, while spiders are important predators of pests.

All three taxa fit Pearson's criteria well and could be used within the scope of a community monitoring assessment. However, it is pertinent to ask how the choice of group would affect the conclusions made from a community study at a polluted site? To examine the relationships between the results of monitoring studies with these three taxonomic groups, results of studies with earthworms, woodlice and spiders along a pollutant gradient are compared. To assess the community responses of each taxon, the groups were surveyed at sites in the region around a zinc, lead, cadmium smelting works situated at Avonmouth, in the south-west of England. This region is contaminated with high concentrations of cadmium, copper, lead and zinc derived from emissions from the smelter.

TABLE 1. The suitability of three invertebrate taxa for community monitoring as described by their correspondence to the seven characteristics for an assessment group detailed by Pearson [19] Groups are scored to a maximum of five for each property except for "relations to other taxa", as it was considered that insufficient data was available to score for this characteristic (see text)

Criterion	Earth-worms	Isopods	Spiders
Taxonomic stability	3	4	4
Knowledge of natural history	5	5	4
Surveyability	3	5	4
Distribution of higher taxa	5	4	5
Habitat change sensitivity of lower taxa	3	3	5
Economic importance	5	2	4
Sensitivity relations to other taxa	?	?	?
Total	24	23	26

At sites closest to the smelter, metal concentrations of 300 μg Cd g^{-1}, 3000 μg Cu g^{-1}, 15,000 μg Pb g^{-1} and 35,000 μg Zn g^{-1} have been recorded [29] and grid based soil sampling has indicated an exponential decline in metal concentrations with distance from the factory (see [30, 31, 32] for a full discussion of the spatial distribution of metals in the Avonmouth area).

The aim of this study was to determine the community responses of these groups to the high soil metal concentrations to ascertain the interrelationship of results from monitoring studies with different groups. For each taxon, a number of community based parameters were considered. These were total abundance (total catch), total number of species, mean number of individuals per species, Shannon-Wiener diversity, total biomass and mean individual biomass (see [33] for details of parameters).

5. Details of the study

Results from two separate studies are given. For the first study, the populations of earthworms at 22 sites in the region around the smelter were assessed by collection from four 0.25 m x 0.25 m quadrats at each site. All earthworms were weighed and identified using the key of Sims and Gerrard [22]. In the second study, spider and woodlouse populations were measured at five sites during July 1994, the peak period of abundance for spiders. At each site, six pitfall traps were laid. These were then left for one month after which they were pooled and all spiders and woodlice that had entered the traps identified to groups, family and ultimately, where possible, species. The biomass of woodlice and spiders was not determined.

A number of papers have been published criticising the use of pitfall traps for the assessment of ground active invertebrate populations [9]. Catches from pitfall traps can be influenced by factors including species, sex, hunger level, pattern and spacing of traps, size, climate and season. There is also a growing volume of evidence suggesting that certain species such as carabids and linyphiid spiders can actively avoid traps and thus catches are reduced [34, 35]. Sunderland *et al.* [9] concluded that the correct term to describe the catch of pitfall traps should be "activity-trappability-density" to alert authors that trapping efficiency varies between species and habitat. However, in this study, "total catch" will be used.

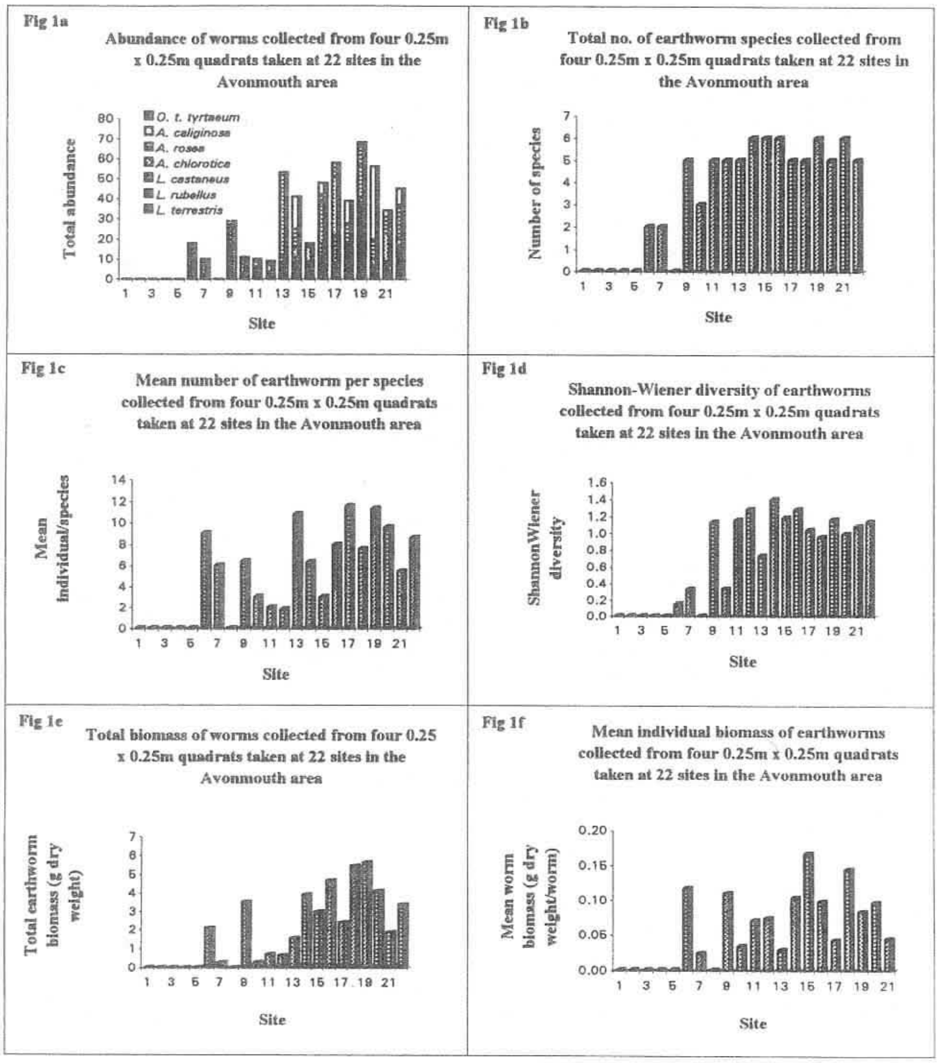

Figure 1. Changes in earthworm communities as indicated by effects on six parameters at 21 sites in the region around a smelting works situated at Avonmouth in south-west England (Sites 1-21) and an unpolluted control site (Site 22). Site 1 is situated within 0.5 km from the smelting works, Site 21 is 10 km from the factory, while Site 22 is over 100 km distant from the pollution source. Six different community parameters are given in the figures a to f.

6. Community response to a gradient of metal contamination

6.1. EARTHWORMS

Earthworm abundance was reduced at sites up to 3 km from the factory. Of particular importance was the absence of all earthworms from the five closest sites (Fig. la). Lack of worms is almost certainly responsible for the considerable accumulation of undecomposed leaf litter at site close to the smelter [31]. If the abundance data for the individual species are analysed, it is clear that there are differences in sensitivity Three species, *Aporrectodea rosea, Allolobophora chlorotica* and *Aporrectodea caliginosa* were more sensitive to metals, since these were absent from sites close to the smelter where *Lumbricus rubellus, Lumbricus castaneus* and *Lumbricus terrestris* persisted (Fig. 1a).

Differences in sensitivity between earthworms resulted in a decrease in the number of species collected from an individual site (Fig. lb). However, the absence of species from the fauna was not accompanied by increasing the abundance of more resilient worms. As a consequence, the mean number of individuals per species was not altered at any of the sites from which worms were collected (Fig. lc). Shannon-Wiener diversity showed a marked decrease with increasing soil metal concentrations. Lowest diversities were recorded at the sites nearest to the factory where the least number of species were present (Fig. 1d).

Total earthworm biomass decreased with distance from the smelting works, reflecting the decrease in earthworm abundance at sites close to the smelter (Fig. le). Mean individual biomass did not show any clear trend (Fig. lf). Thus, there is no evidence for a change in the size structure of the earthworm populations at the most contaminated sites.

Abundance, total number of species, diversity and biomass all showed a logarithmic pattern of decline with increasing proximity to the smelter. As a consequence, it is possible to fit logistic models to the data to calculate EC_{50} values for each of these parameters. For these calculations, the toxic unit (TU) model of Sprague [36] has been applied to determine a value based on the assumption of the additive effects of metals. Although as stated by Spurgeon *et al.* [37] and Spurgeon and Hopkin [29] the most important toxic effect for earthworm populations at sites close to the smelter is due to the effects of zinc. Calculation of EC_{50} values for abundance, total number of species, diversity and biomass gave values of 2.45, 7.35, 4.6 and 1.75 TU g^{-1} respectively. Values could not be calculated for number of individuals per species and mean individual biomass, since these parameters did not decrease sigmoidally with increasing metal concentration. It is noticeable, that the lowest values are for the parameters that show greatest inter-site variation (biomass and abundance). This inter-site variability gives a shallow slope for the logistic regression and thus lower EC_{50} values are calculated.

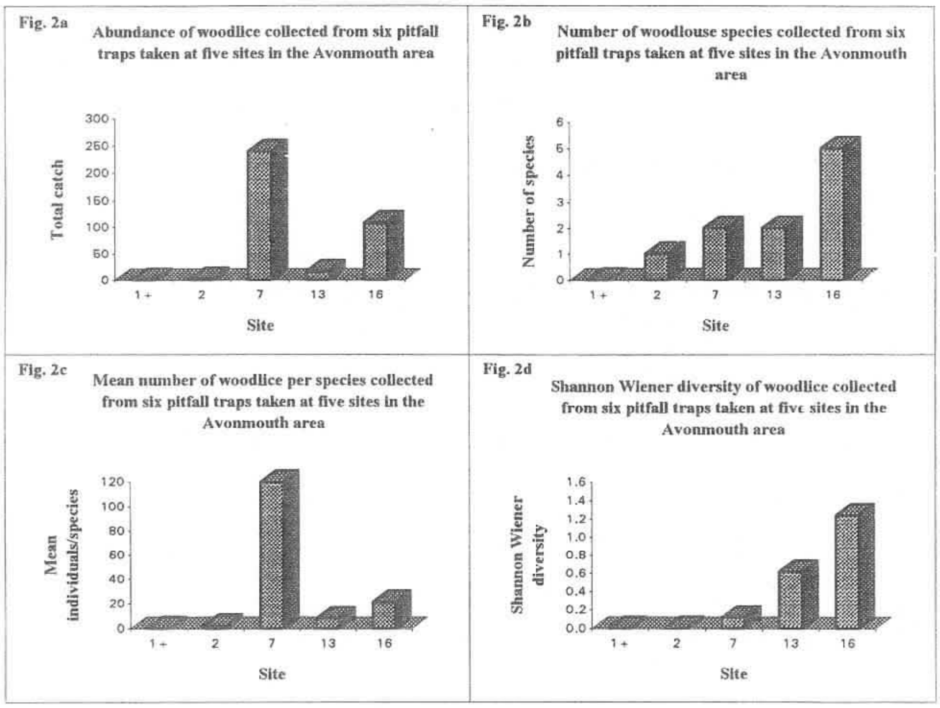

Figure 2. Changes in isopod communities at five sites in the region around a smelting works situated at Avonmouth, south-west England, as indicated by effects on four measured parameters (figures a to d). Sites are numbered with reference to the previous earthworm community study (see legend to Figure 1). Site 1+ is located closer to the smelter than any site previously used.

6.2. WOODLICE

A clear trend for isopod catches to decrease was not found, due primarily to the low catches at Site 13. The differences in total catches at the less contaminated sites indicate that there is high inter-site variability. However, a reduction in catches at the most contaminated site was recorded, with all isopods absent from the two most contaminated sites (Fig. 2a). The number of isopod species was clearly reduced by increasing metal concentrations in soil. Three isopod species, *Philoscia muscorum, Trichoniscus pusillus* and *Androniscus dentiger* were present at Site 16, but were not recorded at any of the four remaining sites. At these sites only *Porcellio scaber* and *Oniscus asellus* were present. Despite the reduction in the number of species, no consistent pattern in reduction

of the number of individuals per species was found at any sites where isopods were present (Fig. 2c).

Isopod diversity was lower at sites close to the smelter (Fig. 2d). Because of the low number of sites used, it is not possible to fit logistic curves for the calculation of EC_{50} values. Consequently, it is not possible to state, which parameter is most sensitive for assessing the impact of metals on isopod communities. However, from the data, it is clear that species number and diversity are among the most sensitive parameters, while number of individuals per species is least sensitive.

6.3. SPIDERS

Surprisingly perhaps, the total catches of spiders tended to increase at sites close to the factory (Fig. 3a). In particular, number of lycosid spiders of the *Pardosa* genus increased greatly. Both increases in the actual abundance of spiders and raised activity of individuals could account for the increase in total catches. The high concentrations of metals present at Site 1+ (over 5 % of the soil dry weight) result in a sparse vegetation cover in areas of the site. The presence of bare soil patches is known to favour ground hunting spiders such as lycosids, which like to bask and hunt in the open. However, there was also a reduction in the catches of some prey groups in the Site 1 pitfalls. For example, springtail and mite catches were reduced, although the numbers of ants and particularly orthopterans are increased (Sandifer, unpublished data). The decreased abundance of some prey may demand that spiders hunt over a larger area to increase their chances of capture.

No clear reduction in the total number of species was found at the most contaminated sites, indeed, like total catch, the number of species tended to increase with increasing metal concentrations (Fig. 3b). The number of individual per species found at the sites closest to the factory was also increased at the most contaminated sites, due primarily to the high catches of lycosids (Fig. 3c). Spider diversity was slightly reduced at the most contaminated site (Fig. 3d). This decrease can be related to the increased lack of equilibrity resulting from the increase in lycosid numbers.

7. Implications of the results for the development of community monitoring systems

Results from community studies with the three chosen taxa indicate the range of sensitivity existing between groups in their responses to soil pollutants. As a result of these differences, the conclusions drawn from studies with individual groups can vary considerably, depending on the taxa choosen for monitoring. In the Avonmouth area, sampling of spider

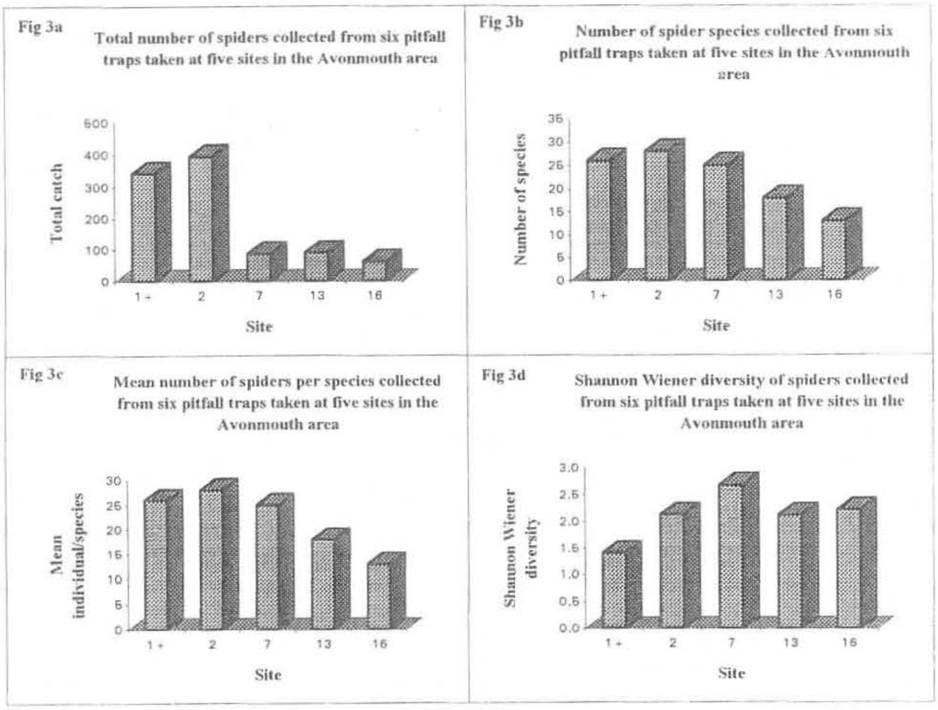

Figure 3. Changes in spider communities at five sites in the region around a smelting works situated at Avonmouth, south-west England, as indicated by effects on four measured parameters (figures a to d). Sites are numbered with reference to the previous earthworm community study (see legend to Figure 1). Site 1+ is located closer to the smelter than any site previously used.

communities would not indicate any gross effects due to metals even at the most contaminated site, while the earthworm community shows effects at sites up to 3 km from the smelter.

Of the three groups studied, earthworm communities appear most suitable for determining the impact of metals, since this taxon shows clear dose-related responses along the pollution gradient. Thus, from this study it could be concluded that earthworms would be an ideal group for monitoring the effects of pollutants at the community level. However, considerable evidence exists to suggest that the relative sensitivities of taxa vary considerably between pollutants. For example, spiders are relatively sensitive to a number of pesticides to which earthworms are comparatively tolerant, whilst, as has been shown, the reverse is true for metals. These differences in relative sensitivity between groups present a fundamental

problem for monitoring with individual taxa. As stated earlier, the search for a "most sensitive species" for laboratory toxicity testing has largely been abandoned because it was concluded that the most sensitive species would vary considerably for each pollutant [38]. The search for a most sensitive indicator taxon for field monitoring may be expected to befall such a fate.

A further problem in community monitoring is that results will be flexible in time as well as space [33, 39]. The development of resistance in invertebrates to the effects of pollutants is a widely recognised phenomenon. Over 500 cases of resistance have been reported among arthropods for pesticides alone [40], whilst a number of species have been shown to develop both physiological and life history adaptations under metal stress [39]. The development of resistance in invertebrate groups may occur at different rates. As a consequence, some species will be able to colonise the most polluted regions of a gradient more rapidly. Knowledge of the development of resistance in different species such as that detailed by Donker and Bogert [41] will be important for the correct interpretation of community study results.

The most sensitive parameter for community assessment also varies between groups. Lowest EC_{50} values for earthworms were obtained for biomass and abundance, although these were also the parameters with the greatest inter-site variation (Figs. 1a-f). For woodlice, the species number and diversity appeared most useful for assessing community structure changes, whilst for spiders, only diversity indicated any deleterious effects at the most contaminated sites. For the latter two groups, measurement of total numbers collected (abundance), appears insufficient to indicate deleterious impact on communities. In these groups, it is essential that individuals are identified to species level to allow calculations of diversity and total species number, if deleterious effects on communities are to be detected.

8. Conclusions

A classic ecotoxicological problem exists that may hinder the development of a successful community monitoring strategy for assessing the effects of pollutants on ecosystems. Regulatory agencies are likely to demand that studies are quick to undertake (and thus have a limited scope), while the demand for successful prognosis of effects means that it is important to undertake surveys of the maximum number of groups, at the maximum possible taxonomic resolution. How can these two conflicting demands be satisfied to develop a non pollutant-specific community biomonitoring scheme?

The results detailed in this paper indicate that it is important to include as many major groups as possible in any survey, as profound effects can

occur for a given group at pollutant concentrations at which other groups appear unaffected. The inclusion of a broad range of groups in a study will result in a large workload if all individuals are to be identified to species. However, if in the initial survey, taxonomic resolution, particularly of the most difficult groups is reduced, this may decrease the workload, while ensuring as broad a scope as possible Alternatively, species level identification could be focused on groups for which it appears that effects on abundance can be detected at the lowest concentration.

Perhaps the most satisfactory system for assessing contaminated sites would be to predict the presence of a number of key species based on the physiological characteristics of the site. Actual fauna could then be assessed to determine if these species are present. The groups where key species are absent could then be subjected to more intense examination to determine trends in the pattern of species removal across the site. This system could be then used to determine the the extent of contamination at a given site and could allow site classification across a broad range of pollutants. Such a "Soil Invertebrate Prediction and Classification System (SIVPACS)", developed with reference to RIVPACS, a system already existing for monitoring the effects of pollutants in freshwater ecosystems (see Section 3), would be a great advance for assessing the impact of soil contaminants at the ecosystem level.

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